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FIRST QUARTERLY PROGRESS REPORT

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Submitted by

Electrical Engineering Research Laboratory
MILLIMETER WAVE SCIENCES

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First Quarterly Progress Report Under NGL 44-012-006 for Period from April 1, 1969 to June 30, 1969

Summary

As described in previous reports and proposals, observations are being made on the planets and the Moon as pertinent information can be best obtained from them. Current observations are being made daily of Venus and Mars as weather permits. The results of these measurements will be reported at the completion of each phase.

For calibration purposes and on a non-interference basis with planetary work, observations are being made of the sun and of radio stars. An attempt was recently made to observe pulsars at 8.6 mm wavelengths. Although the results were negative, it was possible to establish an upper level to their radiation flux at this wavelength. The first measurement of an intensive millimeter outburst at 3 mm wavelength was reported in the last Semi-annual Report and the results of these observations are still being analyzed.

Concurrently with the observations, a program of upgrading of the antenna and receiver is being carried forward. A recent realignment of the antenna successfully doubled the sensitivity of the antenna at 3 mm and gave indication that the antenna may be useful to wavelengths as short as one millimeter. It is our feeling that such use will provide the possibility of obtaining data not available with other systems.

Improvement also appears to be in sight in the receiver quality and in the data handling capacity.

The current report provides a detailed history of the problems associated with the alignment of the antenna. Although this detail will not be of broad interest, it is needed internally for future reference should additional adjustment be necessary. It was included in this report after some hesitation because the same type of problems may have been experienced on other antennas requiring such high precision of surface accuracy and pointing.

First Quarterly Progress Report Under NGL 44-012-006

Section 1. Introduction

This is the First Quarterly Report of Activities of The University of Texas at Austin supported by NASA Grant NGL 44-012-006 (1 April 1968 through 31 March 1972). The grant for the purpose of investigating the millimeter wavelength electromagnetic radiation from bodies of the solar system is directed by Dr. A. W. Straiton and Dr. J. R. Cogdell. This report follows a series of twelve semiannual reports under the same Grant.

Section 2. Millimeter Wave Astronomical Facilities

I. Antenna Polar Axis Alignment

A. Introduction

The pointing accuracy of the 16 foot antenna was measured as part of the evaluation program in the Summer of 1968. The results of these measurements revealed a large component of error attributable to polar axis misalignment, viz., 0.079°. During observations on the radio telescope, the required corrections for these errors proved to be such a bother that it was decided that the alignment should be corrected.

We were advised by Philco-Ford over the telephone that the alignment procedures and pitfalls were delicate matters and should be undertaken under supervision of Philco-Ford personnel. After long and occasionally acrimonious negotiations, it was settled that the authors should meet Mr. Art Brandt at the site to accomplish the realignment.

The work was performed on 10 and 11 June 1969 and was reasonably successful. This report describes the methods used as well as the results obtained. Its purpose is to guarantee that the required information to align the antenna reposes in this Laboratory. Furthermore, some afterthoughts are appended to this report which would be relevent to further tampering with the alignment.

B. Preparation

The agreement we finally reached with Philco-Ford was that our previous evaluation of the errors was to provide the basis for incremental changes in the axis direction. Furthermore, we were to do the postevaluation based upon astronomical techniques. Thus, the technique and results presented in our report, Pointing of the 16 Foot Antenna, by John H. Davis, constituted our primary preparation. We made calculations as to the expected linear motions of the towers to effect the required angular changes. Also, we agreed to make shims for the south tower as well as an iron fixture for attaching a magnetic mirror mount to the axis of the antenna.

Mr. Brandt arrived with an autocolumating theodolite, Kern Model DKM2, a magnetic mirror mount, a magnetic chuck and dial micrometer, a reference mirror, and miscellaneous small pieces of equipment.

C. Alignment Procedures

1. Setup. The basic measurement setup is shown in Figure 1. The mirror is attached to the polar axis and aligned to be perpendicular to the axis (as evidenced by a stationary image with rotating axis) by a trial-

and-error procedure. In our case, the fixture we made for attaching the mirror to the axis did not fit and we modified and used a fixture which Mr. Brandt had brought. Although this fixture was only stable to ±60 arc-sec, we feel that this was no limitation. We overcame this problem by making angular changes in axis angles with the antenna vertical, thereby removing the effects of mirror sag to a high order of accuracy.

2. Elevation alignment. The elevation angle of the axis was adjusted by shimming the south tower. The position of the axis prior to changes was predicted to be

$$el = 30.668° + .079 \cos 27.1° = 30.738°$$

by this laboratory's astronomical measurements. Mr. Brandt measured 30.735° with his theodolite: good agreement considering the mirror sag problem. The angle should be decreased by .070 to make it equal to the latitude of the antenna. Four shim thicknesses were tried before a satisfactory result was obtained: Figure 2 shows the results of shim changes. The original point is clearly anomalous to the others. This unexplained effect caused us to overcompensate at first. The final slope of angle change _vs_ shim thickness which we measured (.850 mdeg/thousandth of inch) was close to the calculated value (1.006). The final position was .003° less than desired, but this was felt accurate enough. This was evenually disturbed slightly during the azimuth corrections.

3. Azimuth alignment. Our original evaluation indicated that the azimuth error of the axis was .036° in the plane of the axis, with the north

tower to be moved west. This angle requires .036°/cos 30.7° = .042° in the horizontal plane. Since no azimuth reference was available, a relative change of .042° was attempted. Several adjustments were made, but it soon became apparent that the theodolite had been disturbed and the original position lost. This left no alternative but to remeasure the axis position by astronomical techniques. This test revealed that the elevation was close, but that azimuth needed to move .012° east. This was accomplished by loosening the bolts on the north tower and moving the tower with the jacking screws. The movement in actual axis angle was about .883°/inch of movement of the base. This fact is relevant to obtaining only an approximate location of the axis: the final fine adjustment came in the tightning of the base bolts. To obtain an acceptable position, it was necessary to tighten first one side and then the other while observing the axis move back and forth in response. This process was repeated several times before a suitable end result was obtained with all the bolts tightened. Our final result was obtained with all the bolts tightened. Our final result was within .002° of the desired location, but since the desired position was based upon an eyeball estimate of the previous night's data, the final result is not necessarily that good.

D. Postevaluation

1. Axis Alignment. The final alignment was accomplished during the morning of June 11, and was checked that afternoon by tracking of Sirius. This star is bright enough to be seen in daytime, but is fairly low in the sky

such that larger refraction corrections must be made. The data are shown in Figure 3. An analysis of this data shows final errors of .007 in elevation and .003 in azimuth, or a total error of .008°. The tracking errors in Figure 3 do not show a clear sinusoidal trend, as the rigid-body model demands, so we are possibly seeing some slight flexure effects in these data. Of significance is the small amount of error around transit, where observations are made when possible. Within ±3 hrs of transit, the track is accurate to ±.003°, a highly satisfactory result.

2. Bearing and Gear Status. After alignment was accomplished attention was directed to the alignment of the bearings and gear. The antenna was rotated to see if the polar bearings were binding, as would presumably be evidenced by audible sounds, irratic driving, high motor currents, etc. No symptoms developed in the simple test.

There was some concern about the possibility of binding between the polar pinions and the bull gear. No direct evidence of binding was observed but it was decided to reshim the drive gear housing and tachometer housings to make sure. Also, the misalignment of the pinion gear circle with the bull gear circle was measured to be about 1.8 arc-minutes, an acceptably low value.

E. Afterthoughts

In conclusion we might mention an idea we had after the work was completed which might possibly be relevant to future corrections should they be required. Mr. Brandt's principal contribution to this work was his appreciation of the necessity of measuring directly in real time the effects of axis changes. This he did with the theodolite-mirror technique with sec.-of-arc accuracy (although flexure and general lack of repeatability made such accuracy meaningless).

Afterward it occurred to us that an alternate means for monitoring these angles would be to boresight the telescope on the State Park Transmitter and use the readout as indication of axis changes. This has one advantage and two disadvantages. The advantage is that this technique would require no additional instrumentation. The first disadvantage is that the adjustments which can be made is the axis direction couple changes into both servo readout angles. Thus it might require considerable hunting around to find the desired location. The other disadvantage is that the State Park direction is close (34.7°) to the equator and thus axis elevation angle couples weakly to the readouts.

II. Antenna Figure Correction

A. Introduction

A major disappointment in the recalibration of the refurbished and relocated 16 foot antenna was the poor patterns which were measured. This fact alone led to a long delay in the calibration program and cast a certain gloom on the entire project. In this section we discuss the state of the antenna as delivered to The University of Texas at Austin by the Philco-Ford Corporation, the diagnostic procedures developed by this laboratory, and the successful corrective adjustments which were made to bring the antenna to near-perfect performance at $\lambda = 3.2$ mm. We also discuss the possibilities of gaining further improvements in the antenna performance for use at shorter wavelengths, say, $\lambda = 2$ mm and beyond.

B. Status of the Antenna Prior to Correction

1. Diffraction Performance of Antenna. The focusing vagaries and best patterns of the antenna are described in pages 13 through 28 of our Technical Report No. NGL-006-69-1, Calibration Program for the 16-Foot Antenna. Our conclusions stated in that report, viz, that the antenna had significantly different focal lengths in the polar and declination directions, has since been confirmed by several techniques.

The diagnosis of the antenna phase errors by its diffraction patterns has been the work of John H. Davis and will be the subject of his Ph.D. dissertation. Mr. Davis has shown that the lowest order phase error term which is detrimental to antenna performance is of the nature:

$$\text{Phase error} = \epsilon (x^2 + a\,x\,y - y^2)$$

where

ϵ = phase error at edge of antenna in radians

x, y = orthogonal coordinant system aligned with ra, dec, axes

a = term describing degree to which quadratic phase error is aligned with natural axes of antenna.

This type of error manifests itself through the antenna patterns in the following ways; The contours on the main lobe of the patterns tend to be elliptical. The eccentricity of the ellipses vary with the axial focusing of the antenna in a manner which indicates the size of the ϵ term. The orientation of theellipses indicate the axis of the errors relative to the natural axes of the antenna. With errors of the sort described by the above equation, the best one can do is compromise focus the antenna for a symmetric beam at the expense of high sidelobes. Figures 4 and 5 show patterns obtained under these conditions.

2. Mechanical Condition. Perhaps the most profitable result of the polar axis alignment work was that it called our attention to the mechanical condition of the antenna. In discussing our poor antenna performance with Mr. Brandt, he suggested that we reshim the backup structure at the points where it is attached to the mount. Somehow, this had never occurred to us before and we immediately saw that his suggestion had strong possibilities. That is, assuming the antenna was correctly designed and constructed, it would "like" to be a parabola. The nonparabolic behavior which we observe in the diffraction patterns could be caused by stresses imparted to the structure by the mount. If this were the case, a correct reshimming could correct the antennas maladies.

After Mr. Brandt's departure we examined the structure in preparation for pursuing this idea. We learned to our astonishment that two of the eight one-inch bolts which held the antenna to the mount were missing. Furthermore, one set of shims was missing and the six bolts which were in place were not very tight. Needless to say, this increased our desire to attempt the reshimming of the antenna.

C. Corrective Procedures

Our corrective procedure consisted of three steps: (1) correcting the axis of the errors to agree with the natural axis of the antenna; (2) removing the quadratic phase errors; and (3) removing higher order errors. We began by taking the contour data. Two adjustments were required before the alignment was satisfactory. Then the quadratic error was removed with one fortuitous shim change. With these corrections, the sidelobe levels and beamwidths were close to theoretical, but the polar pattern was not symmetrical. This was interpreted to be indicative of a higher order phase error of odd symmetry. After two shim changes of an exploratory nature, better symmetry was achieved and the patterns were quite near to the theoretical patterns, Figures 6 and 7 show the final patterns and the theoretical patterns. The remaining assymmetrics can be corrected by transverse adjustments of the feed position. All of the above work was done at a frequency of 94.1 GHz. These corrections improved the gain of the antenna by approximately 3 dB.

C. Summary

The patterns achieved for the antenna are near to the theoretical in beamwidths and sidelobe level. The relative simplicity of these adjustments which produced these results is indicative that the antenna does indeed "like" to be a parabola of revolution. This fact, along with the excellent performance at $\lambda = 3.2$ mm, indicates that the antenna will work well at $\lambda = 2$ mm and possibly at $\lambda = 1$ mm. A mechanical evaluation of the surface accuracy by the manufacturer revealed an rms error of .0025" from the best fit parabola. Based upon the Ruze tolerance theory, scattering losses at 3.2, 2.0 and 1.0 mm should be .26 dB, .7 dB and 2.7 dB, respectively. Thus the efficiency at 1.0 mm would approach 32% if systematic errors could be eliminated.

Our plans are to evaluate and adjust the antenna for operation at $\lambda = 2.0$ mm during the Fall. Operation at 1.0 mm could be achieved with the Josephson junction detectors developed by Dr. Bruce Ulrich of the Astronomy Department. The antenna would be converted to Cassegrain configuration for Dr. Ulrich's use if our evaluation at 2.0 mm indicates potential use at 1.0 mm.

III. Receiver Front End.

During the reporting period a design study of a new 3.2 mm receiver has been done by W. Hung-Su and will be his M.S. thesis. The major conclusions are to use transistor i.f. amplifiers with a bandpass of 1-2 GHz, a tunnel diode second detector, a moving feed Dicke modulator, a modulated neon noise tube for calibration and a Schottky diode mixer of homemade origin (if possible). The components for this new radiometer will be ordered soon. The modulator is being designed and constructed by James E. Gort. The mixer diode development under Prof. R. M. Walser is described in the following section.

The purpose of these paragraphs is to review the current status of our efforts to fabricate improved millimeter wave mixer diodes. This work progress quite slowly during the long session, but has been accelerated during the month of June. It is now believed that both point contact and evaporated Schottky barrier diodes can be fabricated by the end of August.

We are now concentracting on fabricating diodes that can be packaged in the Sharpless type wafers that are in current use in the Millimeter Wave Sciences Lab. We are initially designing for a nominal maximum frequency of 100 GHz and will assume that a 60 MHz IF frequency is to be used. Other detector mount designs can be considered later.

The point contact diodes will be fabricated according to the "recipe" which yielded good electrical characteristics at Aerospace. All the necessary materials are on hand and we have learned to polish, dice, electroplate, and mount the GaAs layers. It remains to mechanically assemble the contacts using the integrated circuit bonding machine in the Materials Lab.

In preparing passivated Schottky barrier devices on GaAs, we encountered two difficulties: (1) the deposition of a suitable dielectric on the substrate, and (2) the preparation of photolithographic masks of sufficiently small geometry and quality to produce low capacity diodes.

The quality of the photo masks is limited by the resolution of the "fly's eye" camera available in the laboratory. Distortion in the lens system limits the useful image to diameters greater than .0005 inch. Images smaller than this lack a sufficient density of reacted emulsion. In connection with this difficulty, a visit was made to the Micro-electronics Laboratory at the NASA Manned Spacecraft Center, Houston, Texas. The individuals contacted at NASA are willing and able to produce the high resolution masks. The resolution available in their camera system was placed at 2.5 microns.

In addition to the high resolution reduction system, a step and repeat camera is available for producing multiple image masks. We are requesting that a set of masks ranging in diameter from 2.5 to 10 microns be produced.

Methods currently available for producing thin film dielectrics require elevated substrate temperatures in the range of 750 to 1000°C. At these temperatures the out diffusion of arsenic results in the decomposition of the epitaxial GaAs layer.

Two techniques for the deposition of SiO_2 seem practical in this case: Pyrolytic decomposition and glow-discharge deposition using organic ortho-silicates. Both methods result in lower substrate temperatures of 400°C and 100°C, respectively. The pyrolytic decomposition of tetraethylortho-silicate seems the more desirable method from the standpoint of process complexity. This process for the deposition of SiO_2 has been implemented in the lab, and the resulting films will be evaluated shortly.

The present program thus consists of several parts:

i) The preparation of SiO_2 films;

ii) evaluation of the physical properties of the films;

iii) evaluation of the electrical properties of the films;

iv) the construction and evaluation of MOS and Schottky barrier devices.

We currently estimate that we will have point contact diodes available for testing by mid-July. However, the fabrication of the Schottky diodes will require the balance of the summer, certainly until the end of August.

IV. Data Recording System

An order for a digital data system has been placed with Non-Linear Systems of Del Mar, California. The equipment is to be used for the timing, digitalization, and recording of the output of our radiometer systems. The A/D conversion is accomplished in such a fashion that the recorded value of the data are proportional to the average value of the video signal during the period of the sampling rate. Thus there is no loss of information and data points are uncorrelated. The data, as well as certain auxiliary information, are punched and printed on a Teletype, Model ASR-33. The timing of the system is synchronous with the clock, with timing period of 1, 2, 10 and 20 sec.

The data recording system records three types of information during each data run: (1) a twenty-five digit thumbwheel input number; (2) three times from the clock; and (3) the data sequence. The twenty-five digit thumbwheel input is printed before and after the data sequence. The times which are recorded are: (1) a time defining the time of the data sequence as, for example, the time of the beginning of the first data timing period and (2) two arbitrary times during the data sequence corresponding to contact closures. Times are recorded to one tenth of a second. The data sequence will consist of typically five to ten minutes of data points, recorded from the integrating voltmeter at times synchronous with the clock. The voltmeter displays the previous reading throughout the integration period for ease of comparison with the printout.

The data system will be delivered in August and will greatly expedite the taking and reduction of data on the 16 foot antenna. The printed output from the system can be analyzed at the site, and the punched tape will be analyzed on the campus computers.

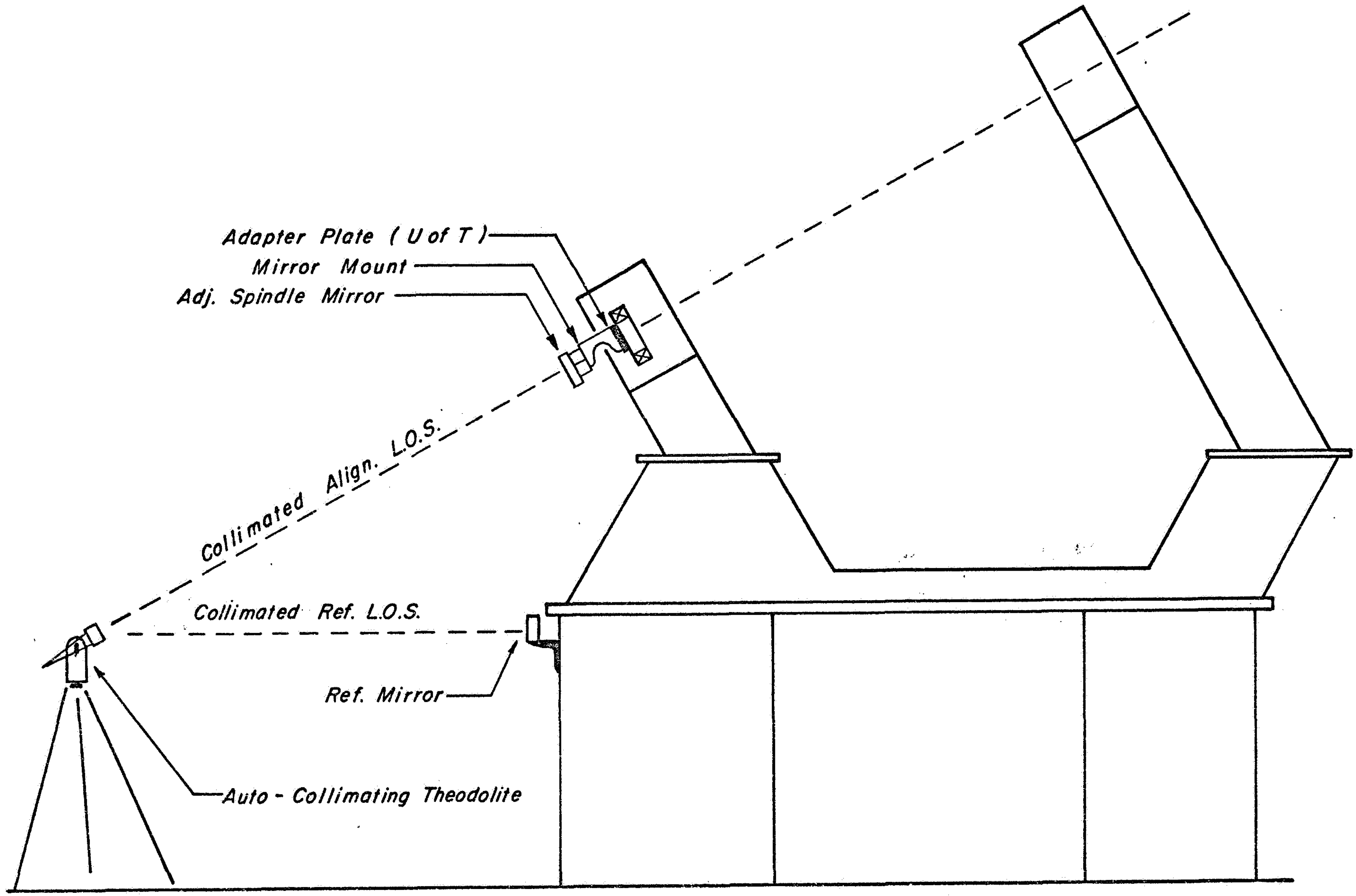
Section 3. Radio Astronomical Observations

A. Venus and Mars.

Observations of Venus and Mars are now being made on a daily basis as weather permits. Data are still being recorded in analog form with strip chart recorders. However, the data are being transcribed in a format which will allow analysis by computer routines designed to operate on the output of the digital system described above. These programs are currently being written.

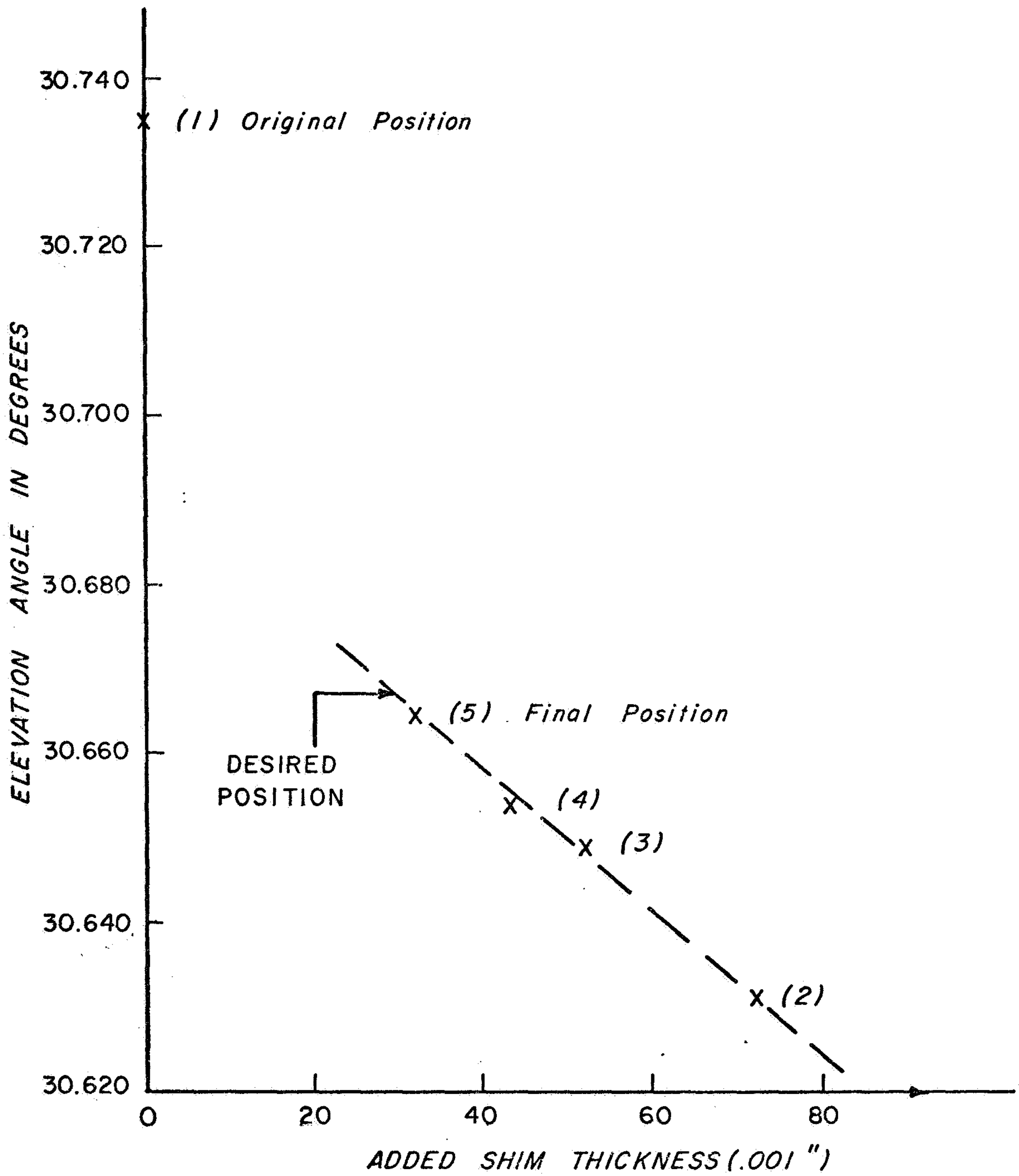
B. Solar Work

The solar microwave outburst which was mentioned in our previous report in this series is still being analyzed. It was necessary to remeasure the antenna pattern and the detector characteristic for a careful evaluation.of the data. Results should be forthcoming in the next Quarterly period.



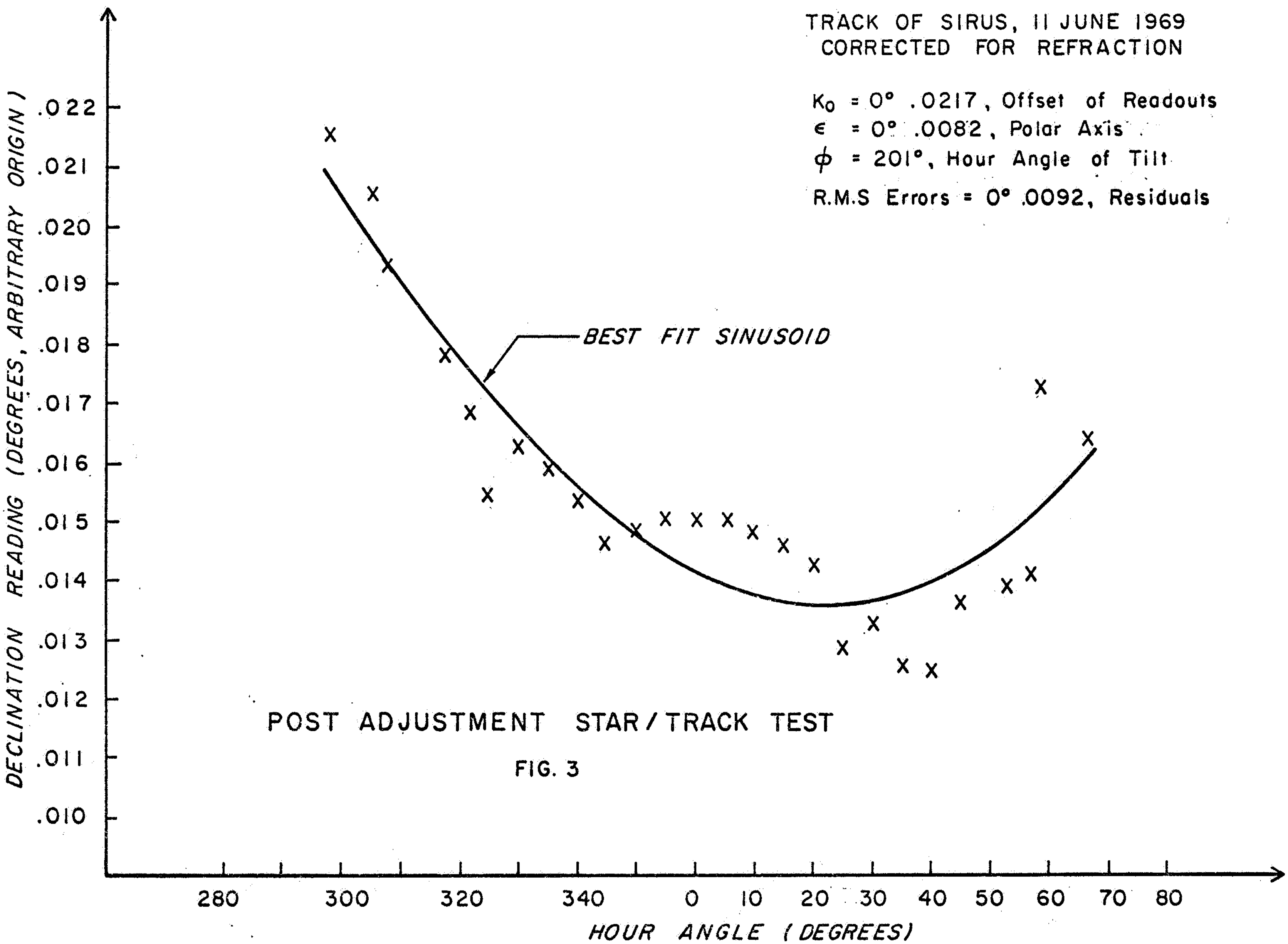
ALIGNMENT SETUP

FIG. 1



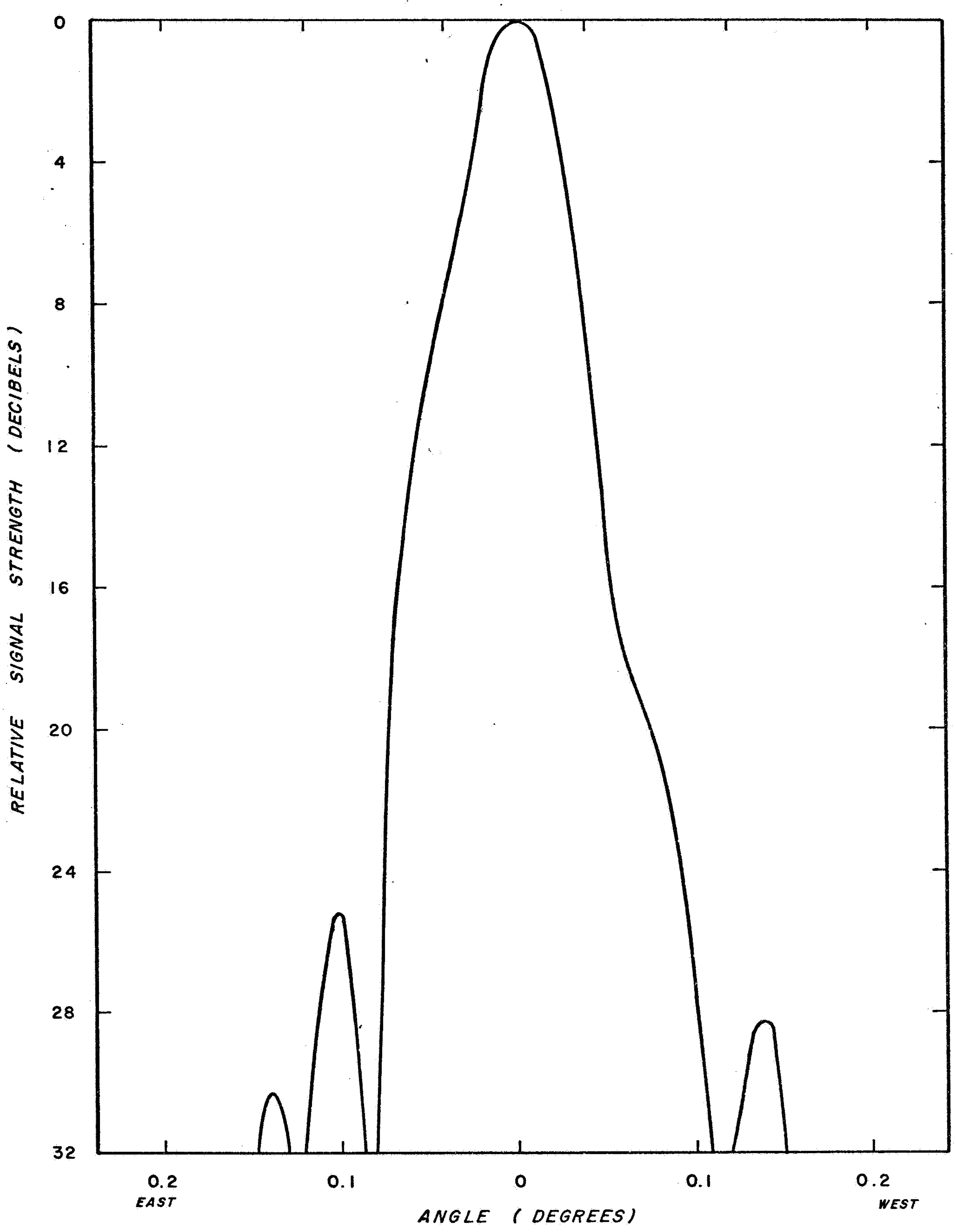
ELEVATION ALIGNMENT

FIG. 2



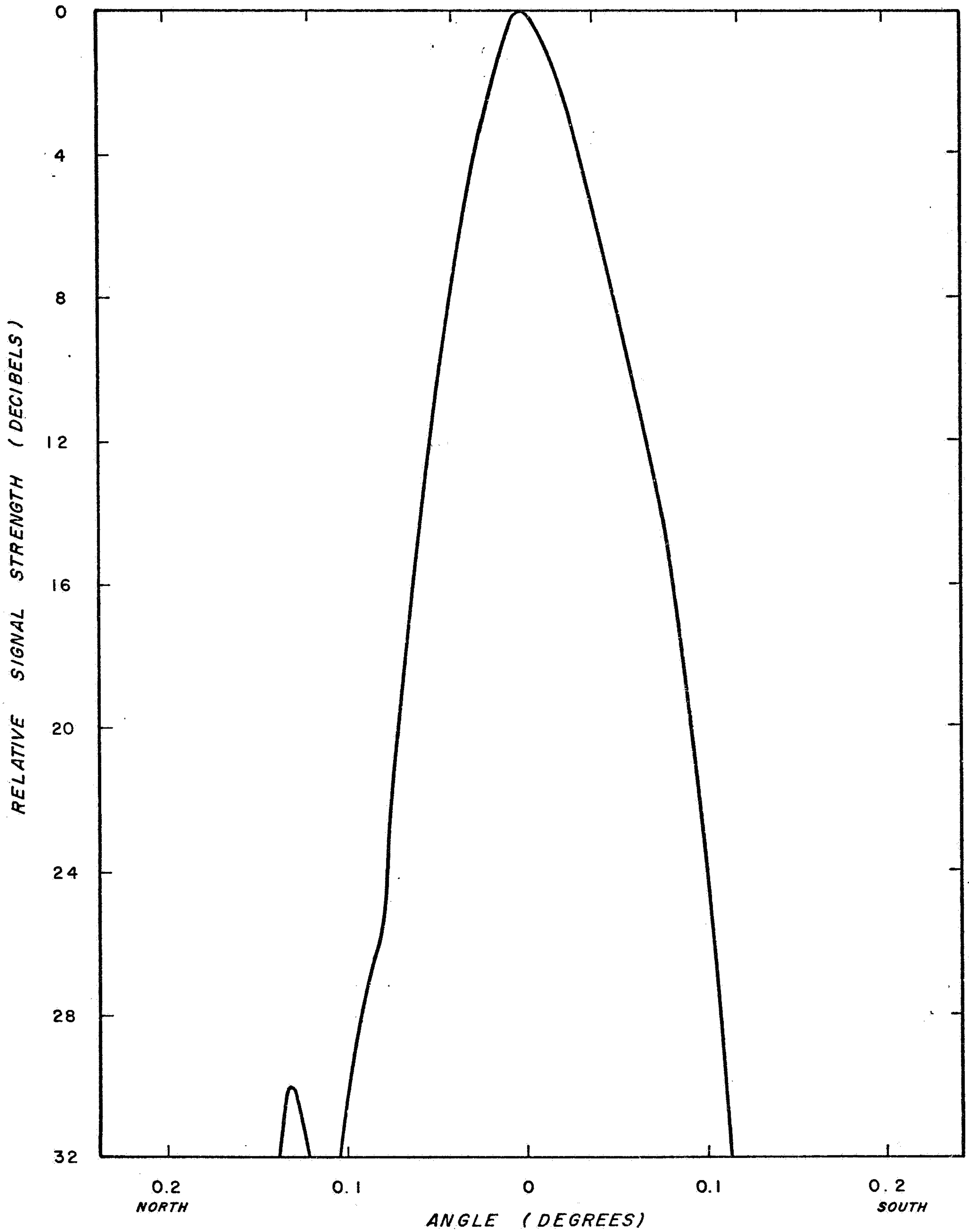
POST ADJUSTMENT STAR/TRACK TEST

FIG. 3



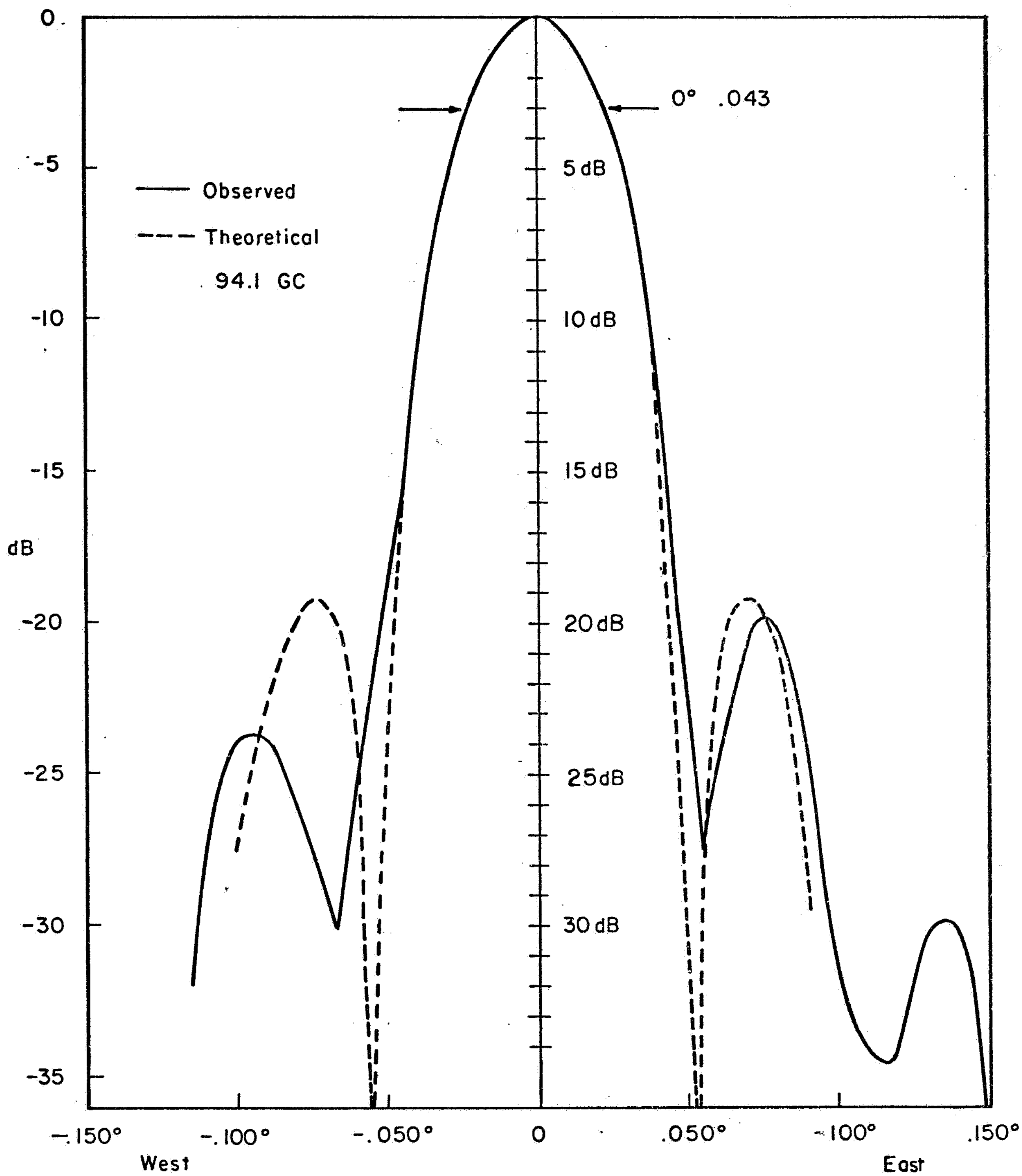
POLAR PATTERN AT 3.1 mm BEFORE ADJUSTMENT

FIG. 4



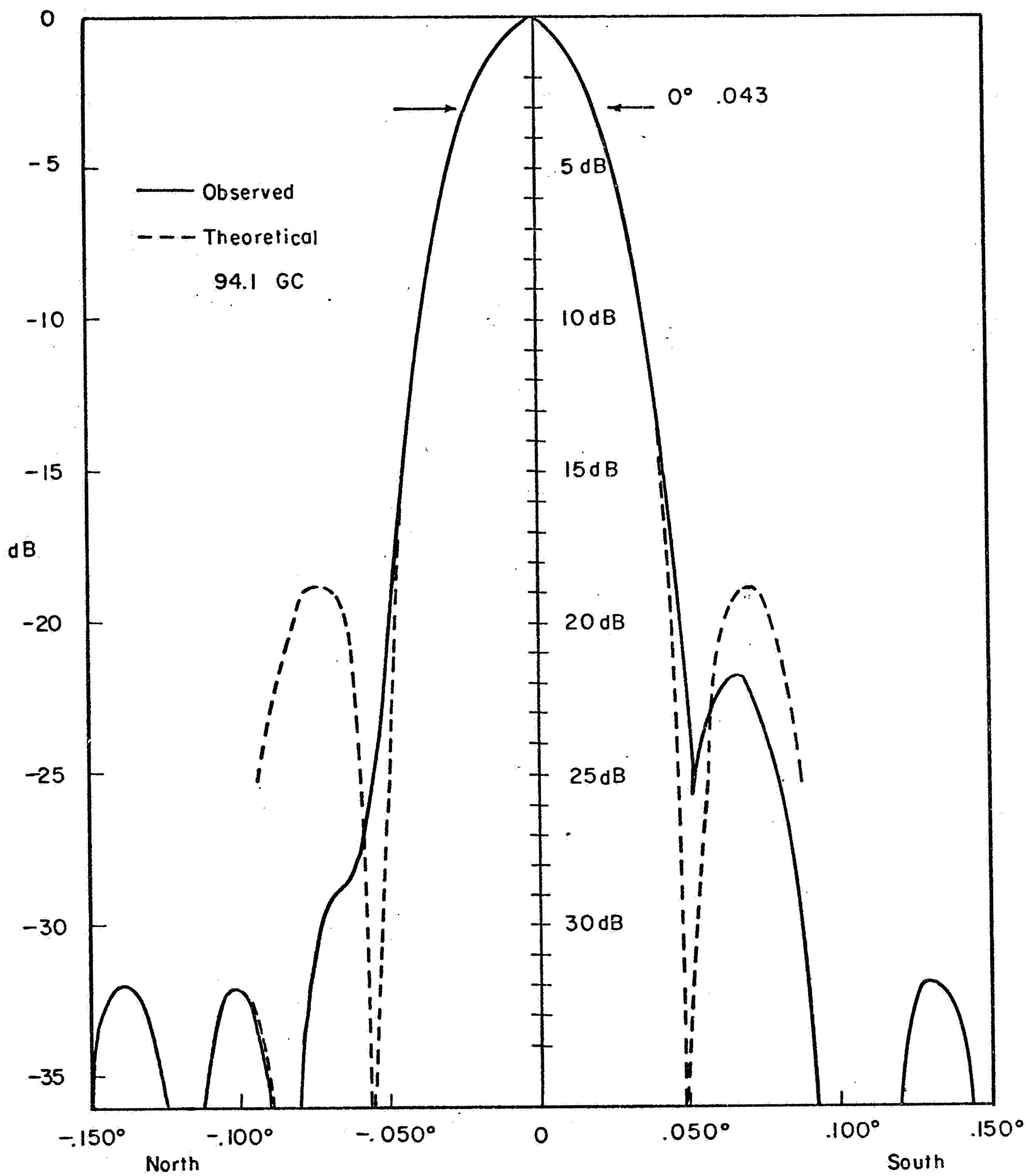
DECLINATION PATTERN AT 3.1 mm

FIG. 5



POLAR PATTERN AFTER ADJUSTMENT

FIG. 6



DECLINATION PATTERN AFTER ADJUSTMENT

FIG. 7